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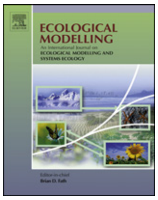

Assessment of a model of pollution disaster in near-shore coastal waters based on catastrophe theory

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ABSTRACT

In this study, a model for assessing of environmental disasters in near-shore areas was developed using a multi-criteria evaluation method of catastrophe theory. The assessment model involved scenarios of eutrophication, pollution with heavy metals and organic compounds. An evaluation system of the model was composed of seven mesosphere indicators and twenty underlying indicators including water chemistry, water physics, water biology, heavy metals and organic pollutants in water and surface sediments. The model was applied to possibility assessment of environmental disasters in different functional regions of the Dalian Bay in 2001 and 2006. Results showed that the environmental disaster indicators in 2001 were equivalent to the Level 4 standard values of marine functional areas, but the eutrophication disaster indicators were lower than the Level 4 standard values. It is consistent with the occurrence of a large-scale red tide in Dalian Bay in 2001. In 2006, eutrophication remained the dominant problem of the region but organic pollutants, such as oil, were reduced remarkably. This coincided with ongoing local environmental-friendly practices for industries.

1. Introduction

As an essential material resource and important environmental resource, coastal wetlands have a significant impact on the maintenance of both regional and global ecological balance as well as the protection of wildlife and their habitats. Rapid economic development and increasing human activities have also resulted in ecological and environmental deteriorations in the near-shore coastal waters and coastal wetlands.

Unlike uncontrollable natural disasters, anthropogenic disasters such as heavy metals and persistent organic pollutants (POPs) pollutions can be prevented and controlled by environmental regulations. Environmental disasters primarily occur in the near-shore coastal areas, especially near city clusters. The typical environmental disasters include eutrophication, heavy metals and POPs pollution. Single scenario models for environmental disasters have been established in China, including eutrophication (An and Tao, 2008), heavy metals pollution (Shen et al., 2008; Chen et al., 2004), and organic contamination (Quan et al., 1996). However, environmental disasters often occur concurrently in near-shore sea regions. Therefore, it is necessary to construct an integrative and comprehensive environmental disaster model.

1.1. The multi-criteria evaluation method of catastrophe theory

Catastrophe theory is a mathematical subject that was created by Rene Thom (Kozak and Benhamt, 1974; Zhao and Xiang, 2002) to study phenomena with discontinuity non-mechanically.

The multi-criteria evaluation method, which is based on catastrophe theory, draws on analytic hierarchy, utility function and fuzzy evaluation to obtain catastrophe fuzzy membership functions by normalized treatment of the bifurcation set. In this method, the dependency of state variables on control variables is determined by the catastrophe fuzzy membership functions, rather than weights assigned by the users. In addition, different control variables have different impacts on state variables in the multi-criteria evaluation method (Li et al., 2007).

The multi-criteria evaluation method consists of the following steps. First, the system is divided into several subsystems with different evaluation indicators according to the inner mechanisms of the system being assessed. The initial data from the underlying layers are then normalized using catastrophe theory and fuzzy mathematics to give the optimal or cleanest data. To accomplish this, multidimensional catastrophe fuzzy membership functions assign values ranging from 0 to 1 to resolve the incomparability of various initial data induced by differences in the data span and dimensions. The total catastrophe fuzzy membership functions of the system are then determined by the normalized data.

When normalizing the initial data from the underlying layers, the cleanest data should be set to 1, after which the remaining data

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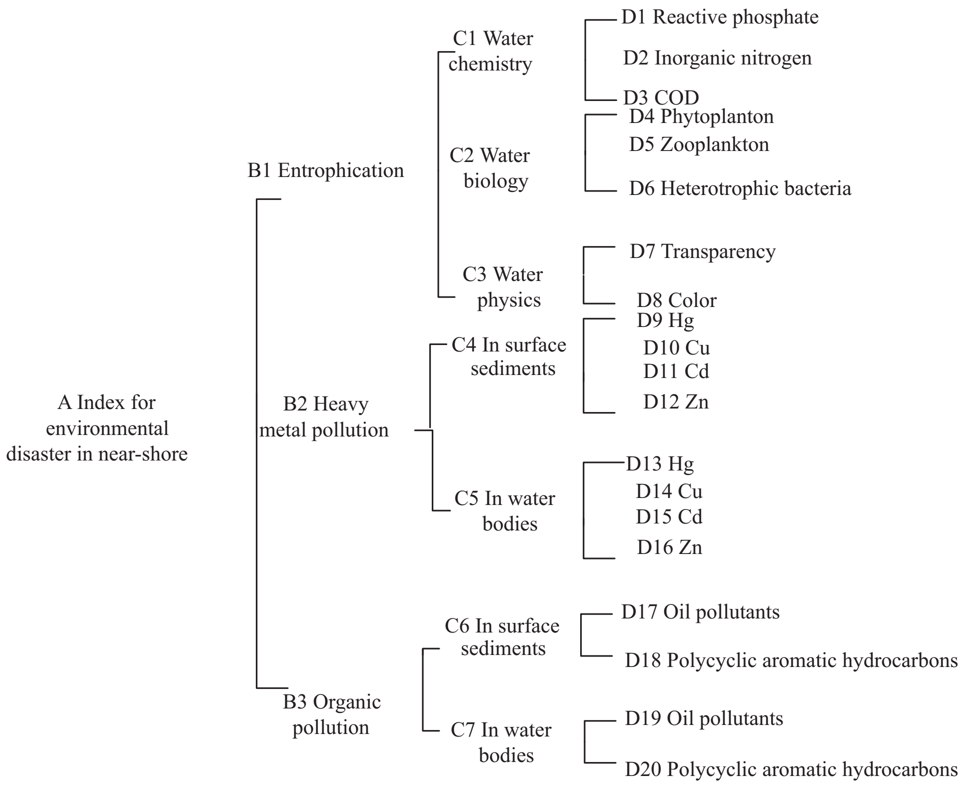

Fig. 1. The near-shore coastal waters pollution disaster indicator system.

are converted to catastrophe fuzzy membership functions with values ranging from 0 to 1.

After being broken down according to their impacts on the higher level indicators, the evaluation indicators from different layers are prioritized. Specifically, there are three types of catastrophe fuzzy membership functions with varying numbers of indicators: the cusp catastrophe, which has two evaluation indicators (a and b); the swallowtail catastrophe, which has three evaluation indicators (a, d, and c); and the butterfly catastrophe, which has four evaluation indicators (a, d, c, and d) (Zhou, 2003).

When using the formula for the normalized data, all indicators of catastrophe fuzzy membership functions in one subsystem are dealt with as follows to calculate the x values:

The cusp catastrophe: $x_a = a^{1/2}$ and $x_b = b^{1/3}$.

The swallowtail catastrophe: $x_a = a^{1/2}$, $x_b = b^{1/3}$, and $x_c = c^{1/4}$.

The butterfly catastrophe: $x_a = a^{1/2}$, $x_b = b^{1/3}$, $x_c = c^{1/4}$, and $x_d = d^{1/5}$.

When performing recursive computations, the principle of minimum values or the principle of mean values is selected after determining if the indicators are complementary to each other or interchangeable within one subsystem (complementary means the impacts of different indicators in the same subsystem on the upper indicator can be replaced by each other).

Formulas are used to perform recursive computation on the normalized data. In the end, conclusions are reached by comparison of different catastrophe fuzzy membership functions from a variety of judgment systems (Li et al., 2007).

The total catastrophe fuzzy membership functions are a group of relative quantities with initial data that varies for the underlying layers, but will not affect the final results.

2. Establishment of a near-shore coastal waters pollution disaster indicator system

The near-shore coastal water pollution disaster indicator system used in the present study was composed of three B layers, seven C layers and twenty D layers, shown in Fig. 1. These layers contained indicators reflecting the properties of water chemistry, water physics and water biology, indicators of heavy metals pollution from surface sediments and water bodies and indicators of organic pollution from surface sediments and heavy metals pollution. All of these indicators include comprehensive factors reflecting the quality of near-shore coastal waters.

2.1. Selection of indicators

In the study, the near-shore coastal waters pollution disaster was set as an indicator, namely as Layer A. The value of Layer A shows the possibility of environmental disaster occurring in the sea area within certain times – the higher the A value is, the smaller the likelihood of environmental disasters becomes, while the smaller the A value is, the higher the likelihood becomes.

Three indicators of the mandatory layer (Layer B) were selected based on three different types of near-shore coastal waters pollution disasters: an eutrophication indicator, a heavy metals pollution indicator, and an organic compound pollution indicator.

Criteria for the selection of indicators for the mesosphere layer (Layer C) were as follows. Based on the influence factors used in two-step fuzzy evaluation of eutrophication, water chemistry combined with water physics and water biology were selected as subordinate mesosphere indicators of eutrophication (An and Tao, 2008). According to the classification of heavy metals in the process of environmental impact and assessment, heavy metals from surface sediments and water bodies are used as subordinate mesosphere indicators of heavy metal pollution. Similarly, based on the classification of organic pollutants in the process of environmental impact and assessment, organic pollutants from surface sediments and water bodies are used as subordinate mesosphere indicators of organic compound pollution.

Criteria for the selection of indicators for the bottom layer (Layer D) were determined as follows: eutrophication indicators, reac-